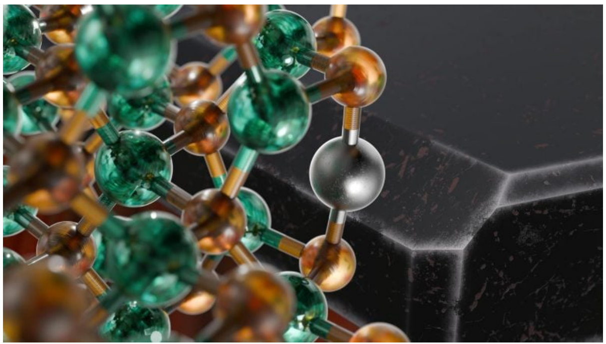
What Occurs When You Exchange Atoms?

Posted by Okachinepa 03/26/2025



Courtesy of SynEvol
Credit: HZDR & TU DRESDEN

A significant issue in their development is accurately controlling their atomic structure, which researchers at HZDR and TU Dresden addressed through cation exchange. This method enables accurate control over nanostructure composition, revealing novel optical and electronic features. The study emphasizes the important function of active corners and defects, which affect charge movement and light absorption. By connecting these nanostructures into structured systems, researchers are opening the path for self-assembling materials with enhanced capabilities, ranging from better sensors to future electronics.

Nanostructures based on cadmium are essential for the advancement of two-dimensional materials that interact with near-infrared light (NIR) through absorption, reflection, or emission. These engagements render them significant for diverse technologies. In medical diagnostics, NIR light penetrates tissues more efficiently than visible light, resulting in clearer images. In telecommunications, NIR materials improve fiber-optic systems, boosting data transmission efficiency. In solar energy, they can enhance the efficiency of photovoltaic cells.

Dr. Rico Friedrich, from the Institute of Ion Beam Physics and Materials Research at HZDR and Chair of Theoretical Chemistry at TU Dresden, states, “It is essential to precisely alter the material to achieve the intended optical and electronic features for all these applications.” “Historically, this posed a challenge as nanochemical synthesis relied more on the trial and error approach of mixing materials,” notes Prof. Alexander Eychmüller, Chair of Physical Chemistry at TU Dresden. The collaborative research project was jointly led by the two scientists.

A key challenge in nanomaterial research is managing the thickness of nanostructures by modifying their atomic layers without altering their width and length. Conventional synthesis techniques find it challenging to attain this level of precision. Cation exchange provides a method by systematically substituting specific positively charged ions (cations) in a nanoparticle with different ones.

This approach provides us with accurate control over the composition and structure, enabling us to create particles with characteristics that are unattainable through traditional synthesis techniques. "Nevertheless, the precise mechanisms and origin of this reaction remain largely unknown," states Eychmüller.

In this ongoing project, the group concentrated on nanoplatelets, where the active corners are essential. These corners are especially chemically active, allowing for the binding of platelets into structured formations. To gain a deeper insight into these effects, the researchers integrated advanced synthetic techniques, atomic-resolution (electron) microscopy, and comprehensive computer simulations.

Active corners and defects in nanoparticles are intriguing not just for their chemical reactivity, but also their optical and electronic characteristics. These locations frequently possess a dense gathering of charge carriers, influencing their transport and light absorption. “Coupled with the capacity to swap individual atoms or ions, these defects could also be utilized in single-atom catalysis, leveraging the exceptional reactivity and specificity of singular atoms to enhance the efficiency of chemical reactions,” Friedrich explains. Accurate management of these defects is essential for the NIR activity of nanomaterials. They influence the absorption, emission, or scattering of near-infrared light, providing methods to systematically enhance optical characteristics.

Another result of this study is the potential to systematically connect nanoplatelets through their active corners, merging the particles into structured or even self-organized arrangements. Future uses might leverage this organization to create sophisticated materials with combined functionalities, like NIR-active sensors or innovative electronic components. In reality, these materials might enhance the performance of sensors and solar panels or enable novel techniques for data transfer. Concurrently, the study also provides essential insights for additional fields of nanoscience, including catalysis and quantum materials.

The team's results were achievable solely due to a mix of cutting-edge synthetic, experimental, and theoretical approaches. The scientists could not only accurately manage the design of the nanoparticles but also examine the function of the active corners thoroughly. Experiments on the distribution of atomic defects and compositional analysis were integrated with theoretical modeling to obtain a thorough understanding of the material characteristics.